

# Finding typical high redshift galaxies with the NOT

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**Abstract.** We present results from an ongoing search for galaxy counterparts of a subgroup of Quasar Absorption Line Systems called Damped Ly $\alpha$  Absorbers (DLAs). DLAs have several characteristics that make them prime candidates for being the progenitors of typical present day galaxies.

## 1. Damped Ly $\alpha$ Absorbers and high redshift galaxies

Damped Ly $\alpha$  Absorbers are QSO absorption line systems with HI column density larger than  $2 \times 10^{20} \text{ cm}^{-2}$ . This very large column density absorption occurs in regions of self shielding, cooled gas, i.e. where we expect stars to form. Hence DLAs are prime candidates for being the progenitors of present day galaxies. This hypothesis is strengthened by the fact that the neutral gas content of DLAs at high redshift, within the uncertainties, is known to be the same as that of visible matter in present day galaxies (Wolfe et al., 1995). Hence, DLAs being HI column density selected galaxies are truly representative of the progenitors of present day galaxies.

There are primarily two pieces of information we wish to obtain via the study of DLAs : (i) the size and (ii) the stellar content of typical high redshift galaxies. Concerning (i), it is a long standing controversy whether DLAs are large fully formed disk galaxies or small merging galaxy subunits (e.g. Wolfe et al., 1986, Haehnelt et al., 1998). The actual size of typical high redshift galaxies will give us information about the nature of the dark matter that forms the haloes containing the baryons. Concerning (ii), it has become clear that the star formation histories of all local group members differ from that of the Milky Way and differ amongst each other. Therefore we cannot expect any single galaxy in the local group to be a good tracer of the global star formation history (e.g. Tolstoy, 1998). Another line of approach that has been pursued heavily in the last few years has been to try to obtain the global star formation history via the study of so called Lyman break galaxies (LBGs) in the early universe. LBGs are found using a technique based on the fact that young, star forming galaxies will have a strong spectral break at the lyman limit, which at high redshift is redshifted into the optical window (Steidel et al., 1996). LBGs need to be bright enough for spectroscopical confirmation of their high redshift so they are typically brighter than  $R(AB)=26$ . Assuming that DLAs arise in gaseous discs associated with LBGs we can compare DLAs and LBGs by calculating how faint we need to integrate down the extrapolation of the luminosity function of LBGs in order to explain the observed probability for a QSO line of sight to cross a DLA. Results of this calculation are presented in Fynbo et al., 1999, and summarized here. At  $z = 3$  we find that 70-90% of DLA galaxy counterparts are fainter than the current limit for

See attached GIF colour image.

**Figure 1.** Results from narrow/broad imaging of two DLA fields with the NOT. Left : the DLA towards Q0151+048A. Right : the DLA towards PKS1157+014.

spectroscopic confirmation of LBG candidates of  $R(AB)=26$ . Hence LBGs are highly atypical high redshift galaxies, probably the progenitors of present day bright cluster galaxies (Baugh et al., 1998). Studying high redshift DLAs is therefore the only way to obtain information about the nature of *typical* (in that they contain the baryons found in galaxies today) galaxies in the early universe.

The most obvious method by which to determine the sizes and stellar contents of DLAs is to detect emission from them.

## 2. Imaging of DLAs with the NOT

From an observational point of view the main problems in studying emission from DLAs are (i) that they are very faint and (ii) the presence of a much brighter QSO at a distance of only 0-3 arcsec on the sky. In the spectrum of the background QSOs DLAs at redshifts  $z \approx 2$  produce regions of 15-25Å (the width depending on the HI column density) of saturated absorption. Hence imaging in a narrow filter with a width corresponding to the width of the damped absorption line will circumvent problem (ii).

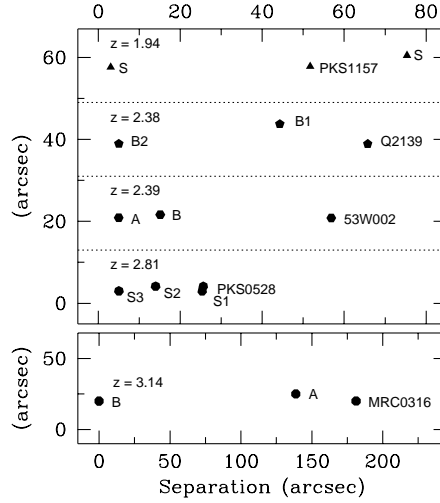
If the DLA is a  $\text{Ly}\alpha$  emitter it will be relatively easy to detect against the modest sky background in the narrow band filter which helps circumventing problem (i). Narrow band imaging of DLAs have been pursued in more than a decade (e.g. Lowenthal et al., 1995), but only recently with success. The DLA at  $z = 2.81$  towards the  $z_{em} = 2.79$  PKS0528-250 (Møller and Warren, 1993, 1998, Warren and Møller, 1996) was detected with narrow band imaging using the ESO 3.6m telescope and confirmed by spectroscopy on the ESO NTT. Here we describe our results on narrow and broad band imaging of the DLAs towards Q0151+048A ( $z_{abs}=1.9342$ ) and PKS1157+014 ( $z_{abs}=1.9436$ ). These two DLAs were chosen because they are  $z_{abs} \approx z_{em}$  systems, as is the DLA towards PKS0528-250. The QSO redshifts are  $z_{em} = 1.921$  and  $z_{em} = 1.978$  for Q0151+048A and PKS1157+014 respectively. Moreover, Q0151+048 is very interesting in being a physical QSO pair (not a lensed system) with two QSOs at nearly the same redshift (Meylan, et al., 1990). The B component has redshift  $z_{em} = 1.937$  (Møller, Warren and Fynbo, 1998). Moreover, the DLA towards PKS1157+014 has one of the highest HI column densities ( $6 \times 10^{21} \text{cm}^{-2}$ ) of all known DLAs. NOT was the perfect instrument for these DLAs due to the high spacial resolution and the very high UV sensitivity of the Loral CCD at the wavelength of redshifted  $\text{Ly}\alpha$  ( $\approx 3600\text{\AA}$ ).

The DLA towards Q0151+048 was imaged in narrow-band, U and I in four nights in September 1996 with StanCam. We obtained  $5\sigma$  point source detection limits of  $n(3567)=24$  (corresponding to  $5.0 \times 10^{-17} \text{ergs}^{-1} \text{cm}^{-2}$  for  $\text{Ly}\alpha$  at the absorption redshift),  $I(\text{AB})=25.7$  and  $U(\text{AB})=26.0$  respectively. The three left panels in fig. 1 show  $100 \times 60 \text{arcsec}^2$  from the combined I-frame (top), U-frame (middle) and narrow band frame (bottom). North is up and east is to the left. Seen are the two QSOs in the center of the frames and a candidate  $z = 1.93$   $\text{Ly}\alpha$  emitting galaxy  $40''$  east of the QSOs. In the lower frame we have subtracted the Point-Spread-Functions of the two QSOs so that the extended  $\text{Ly}\alpha$  emission from the DLA is clearly seen.

The DLA towards PKS1157+014 was imaged in narrow-band, U and I in two nights in March 1998 with Alfosc. We obtained  $5\sigma$  point source detection limits of  $n(3567)=23.2$  (corresponding to  $7.5 \times 10^{-17} \text{ergs}^{-1} \text{cm}^{-2}$  for  $\text{Ly}\alpha$  at the absorption redshift),  $I(\text{AB})=25.9$  and  $U(\text{AB})=25.3$  respectively. The three right panels in fig. 1 show extractions from the combined I-frame (top), U-frame (middle) and narrow band frame (bottom) with the same field size as the left frames, but with north to the left and east down. Seen are the QSO in the center and two candidate  $z = 1.94$   $\text{Ly}\alpha$  emitting galaxies. In the lower frame the QSO has completely vanished due to the extremely strong damped absorption line. There is no evidence for  $\text{Ly}\alpha$  emission from the DLA at impact parameters smaller than  $10''$ .

### 3. Discussion

It is not yet possible to draw general conclusion about the nature of DLA galaxies based only on the few DLA galaxy counterparts currently studied in emission. We do, however, note that in all three DLA fields studied with narrow band imaging so far we have found one or more candidate galaxies at the DLA redshift. In the right frames of fig. 1 the two galaxies seem to be aligned with the QSO. As noted by Møller and Warren, 1998, there is growing evidence for filamentary structure in the distribution of  $\text{Ly}\alpha$  emitting galaxies at high redshift. Fig. 2 is an updated version of their Fig.6 showing alignments in 5 galaxy groups at high redshift, including the field around PKS1157+014. This trend is in agreement with N-body simulations of hierarchical structure formation where galaxies predominantly form along filaments (e.g. Evrard



**Figure 2.** Evidence for alignment in groups of  $Ly\alpha$  emitting galaxies

et al., 1994).

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